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The EFP-94 Project on Safety Systems for Wind Turbines

Method for Evaluation of Failure Modes and Reliability

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Risø National Laboratory, Roskilde, Denmark
September 1996

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Hans Erik Kongsø, Igor O. Kozin, Palle Christensen

Risø National Laboratory, Roskilde, Denmark
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Abstract A project sponsored by the Danish Energy Agency was carried out in co-operation with two Danish wind turbine manufacturers. In accordance with the purpose of the project a methodology for the analysis of the reliability of the safety systems of wind turbines was established in addition to a supporting database for reliability data of wind turbine components and equipment. The methodology and database were implemented on PCs and comprise a fairly unique facility, which provides advanced on-line reliability analysis of the two wind turbine safety systems using realistic reliability data, based on maintenance- and repair reports in addition to statistical analysis of the empirical data. The reliability analyses can be performed on a component, subsystem and safety system level as required. The integrated methodology and database has great potential for applications for design and maintenance planning also on other technical systems than the ones analysed within this project.

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1. Introduction

The current work was carried out under a research project entitled 'EFP-94/ Safety Systems for Wind Turbines: Method for Evaluation of Failure Modes and Reliability'. The project was sponsored by the Danish Energy Agency and was carried out in co-operation between Risø National Laboratory (Departments: Systems Analysis and Meteorology and Wind Energy), BONUS energy A/S, NORDTANK A/S and ELSAMPROJEKT A/S.

The project was carried out in continuation of a pre project entitled 'EFP-92/ Sikkerhedssystemer for vindmøller'.(Safety Systems for Wind Turbines).[5].

The purpose of the project was to develop a methodology for the analysis of the reliability of the safety systems of wind turbines (WTB) and to establish a database with reliability data for WTB components and equipment.

This report contains the description of the proposed methodology, the work required for establishing the basis for the analyses, the database made and some of the programming details intended for the people who want to modify the database. This report has three appendices. Appendix 1 and 2 are classified since they contain confidential information about the design of the wind turbines. Appendix 1 contains FMECA tables and fault trees prepared for the BONUS 450 kW Mk III wind turbine safety system, and appendix 2 - the corresponding material for the NORDTANK 150 kW NTK 150 XLR wind turbine safety system. Appendix 3 contains details on database objects.

Concerning the terminology used see for instance [6].

2. Methodology

2.1. General structure of the software

In order to meet the purpose of the project software was created to perform the reliability analysis of the safety systems of WTBs based on operational failure data collected in the database, Failure Mode, Effects and Criticality Analysis (FMECA) tables and reliability models. The general structure of the software can be drawn as it shown in Fig. 2.1.

The software consists of a few modules and presents to the users the two main groups of capabilities: 1) informational capabilities which help to screen desirable information and to answer the questions: How many failures for a particular system/component have happened? Dates of failures? Who is responsible? What are the causes? and so on (all of them are obtained within the database); 2) computational capabilities, such as the evaluation of the probability of the top event (in this project: overspeed of the rotor), the probability of failure of a specified system, listings of dominating failure modes in order of decreasing importance with respect to cut set order or a specified parameter like for instance frequency and/or consequence, restoration time, or unavailability.

More complicated parts of the computational capabilities is performed by the separate group of programs activated from the database as described in section 2.6 below.

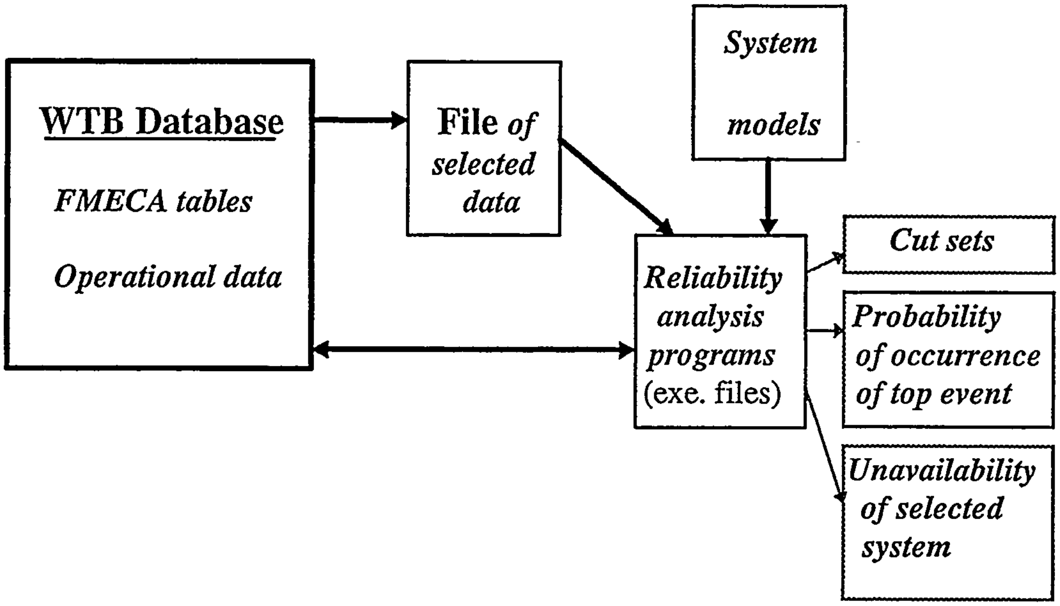

Figure 2.1. General structure of the software

Among these is Risø's FAUNET program package [1] which contains programs for calculating minimal cut sets of the tree, the unavailability of the system at various time points from the minimal cut sets, and failure and repair data for the components extracted from the database on the basis of the failure reports entered as shown in Fig. 2.1. Some simple computational capabilities are provided within the database: calculation of failure rates, mean repair times for chosen components or systems and the number of occurrences, and others.

Realising that for some components and systems failure occurrences will be absent in the database or the number of them will be insufficient for obtaining appropriate statistics for the data assessments, the user has three choices: 1) to get lower probabilistic assessments (if we do not have failure occurrences for a component, the failure rate is considered equal to zero); 2) to get upper probabilistic assessments (we consider that one failure has happened for a component without failures until now); 3) to use manually inserted failure data from other (generic) sources.

All possible manipulations with the software are made from the database.

2.2. Event Sequence Analysis

Event sequence analysis is made to determine the response of the wind turbine to initiating events. Initiating events are occurrences that causes disturbances in the normal functioning of the wind turbine, which require control or safety actions in order to prevent serious damage of the wind turbine or hazardous situations for the environment. Initiating events and other environmental conditions taken into account in the current reliability analysis are listed below (Table 2.1):

Initiating events and conditions	Rate of IE
Init. events gr. 1 (-lightening)	0,0017
Wings rotate, v> 5 m/s	0,98
Init. events gr. 2 (lightening)	0,000011
Gr. 1 - emergency stop	0,00017
Gr. 2 - emergency stop	0,000057
Wind speed: 5<v<=10m/s	0,42
Wind speed: 10<v<=20m/s	0,29
Wind speed: 20<v<=25m/s	0,01
Init. events gr. 3, v> 25 m/s	0,000012

Table 2.1. Initiating events and environmental conditions.

An event sequence model contains sequences of events that, following an initiating event, lead either to a successful state or to a fault state. The events that follow an initiating event are called "secondary events". These events usually concern the detection of the initiating event, the triggered control and safety actions, or an operator intervention. Secondary events involving failure of safety related equipment may lead to an unwanted end state. For example, after an initiating event is being detected, the control system will mostly bring the wind turbine to a parked situation. If the detection or the shut-down action have failed, the wind turbine may reach a failed state.

Event Tree Analysis (ETA) and Cause-Consequence Analysis (CCA) are two techniques commonly used for developing event sequences.

A Cause-Consequence Analysis is a method that follows the chronological or causal order of events. The result of a CCA is a Cause-consequence diagram that displays the causes of events and the resulting consequences by proceeding in two different directions. In the current project a cause-consequence diagram for the safety system has been worked out where only one unwanted event was of interest, namely "overspeed of the rotor" (see Fig. 1 in Appendix 1 and 2 (BOTH CONFIDENTIAL)).

An event tree analysis is another method for performing event sequence analyses. The result is an event tree diagram, where the initiating event and the secondary events are mapped out, assuming a branch for both success and failure. Four event trees have been worked out for different environmental conditions, for different wind speed ranges: 5 m/s < v < 10 m/s; 10 m/s < v < 20 m/s; 20 m/s < v < 25 m/s; v > 25 m/s. These event trees are shown in Appendix 1 and 2, chapter 3.

Both methods, ETA and CCA, have their own advantages and disadvantages (for details see [4]) and it was decided to use both approaches to analyse the safety system thoroughly, see Appendix 1 and 2. A CCD can contain more information than an event tree because it allows for more complex branching than on the Yes/No logical operator allowed in the event trees. The compactness of a CCD compared with event trees also has its drawbacks. Grouping of the branches makes sequence by sequence review difficult and some dependencies may be overlooked.

2.3. Failure Mode, Effects and Criticality Analysis

Before a detailed evaluation of the reliability characteristics can be started, it is necessary to identify all failures of interest within the systems (subsystems) included in the event sequence diagrams. Failure Mode, Effects and Criticality Analysis (FMECA) is a very effective and systematic tool for this purpose. FMECA has formerly been used successfully for safety assessments of wind turbines, see [2-4]. The current work also includes this kind of analysis (see Appendix 1 and 2).

In general the method works as follows: Once the boundaries of each of the systems/subsystems have been defined, it is subdivided into its components. The components must be assessed one by one for possible failure modes and their potential effect on the whole system. A classification of the failure modes can be done through a criticality analysis, in which values for likelihood are assigned to the failures and values for severity are assigned to the effects, which then are combined to give a criticality category.

FMECA can be used to check and improve a design, but also to analyse an operating system. It generates a- for this purpose- very useful qualitative, systematic reference list of components, failure modes and effects, as well as a ranking of failures, so that components that require further investigation are highlighted. Thorough recommendations for performing the analysis are described in [4]. The FMECA tables contain the following information: *system and component identification, failure mode,* *failure cause, detection method, responsibility, likelihood, basic event type* and some additional fields needed for the purpose of structuring the database.

2.4. System modelling

There are three purposes of a detailed modelling of the systems involved in the event sequence:

1. to identify the components and failure modes that contribute to (safety) system failure (or success) associated with the secondary events (top events, heading events) in the event sequence analysis;
2. to estimate the probability of occurrence of the upper top event of the analysis and the unavailability of the systems;
3. to assess the relative importance of the constituent components of the systems.

Several system modelling methods are available. A fault tree is a graphical tool that is very common in system analysis when an undesired state of the system (a top event) is specified. The system is analysed in detail, within the context of its environment and operation, to determine all possible ways in which that event could occur. A fault tree addresses the ways a system can fail to perform its intended function. It is a graphical model that represents the combinations of individual component failures or other events that lead to the occurrence of the undesired state.

The modelling method selected in this project is nodal, based on logical block diagrams as shown in Appendix 1 and 2. A computer program *binput.exe* automatically converts the nodal file into a fault tree file and a rudimentary basic event data file serving as input for the CUT computer program as described in chapter 2.6 below.

2.5. Data analysis

Data analysis implies the overview of the data obtained according to the users specification by queries. The results are presented in an aggregated outlook, and if required, the data can be treated by some formulas, the outcome of which is easily traceable. It has been decided to analyse the data at three levels: 1) component, 2) system, and 3) wind turbine as a whole.

All possible predefined options at the three levels available for the user are depicted in Fig. 2.2.

The result of any end state in the chain of choices is a resulting report containing aggregated information concerning failures. For example, if the user chooses the chain "*System level - All WTBs*", as the result of this action the report shown in Fig. 2.3 will be formed.

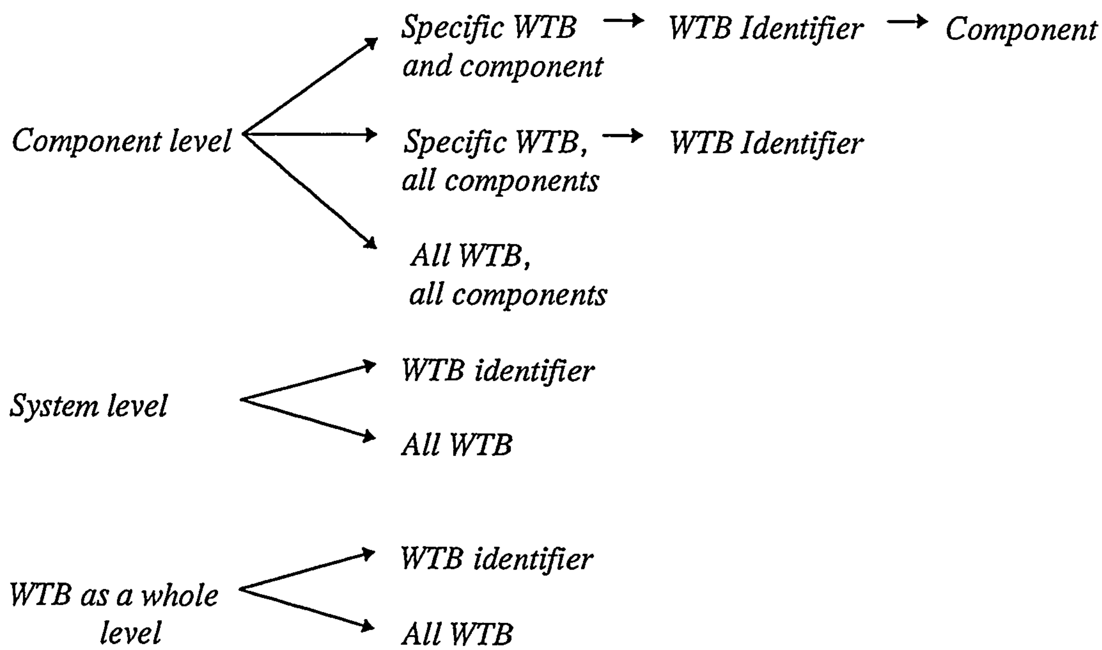

Figure 2.2. Data analysis options.

System Failures by *26-Apr-96*

WTB Type XX   Number of WTB units in the database: XX

System		Total Repair Time	Mean Repair Time	Number of failures
C	XX	RT	RM	NF
H	XX	–	–	–
K	XX	–	–	–
L	XX	–	–	–
O	XX	–	–	–
P	XX	–	–	–
R	XX	–	–	–

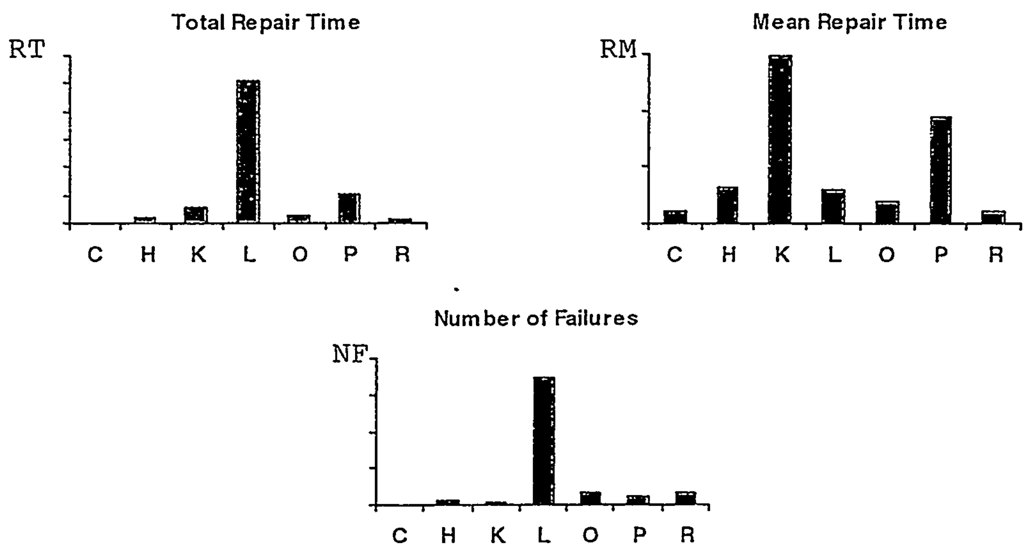

Figure 2.3. Presentation of results of a data analysis (original figures and system designations deleted).

2.6. Reliability calculations

The reliability calculations are performed in accordance with the methodology described in section 2.1.

The reliability calculations, which can be performed as specified by the user is done by clicking the box ‘ Reliability Analysis’ on the main menu.

In addition the top event number to be analysed must be clicked on the form called ‘Unwanted Events’.

The reliability calculations are performed by executing the following sequence of computer programs:

1. BINPUT.EXE, NINPUT.EXE

The program BINPUT(BONUS) and NINPUT(NORDTANK) respectively generate the fault tree input file (B5500.FLT) for the computer program, CUT (CUT.EXE), from Risø’s FAUNET program package on the basis of the nodal system model files B5500.INP and N5500.INP for the BONUS and NORDTANK wind turbines respectively. In addition it generates a rudimentary basic event file (B5500.DAT).

2. BIKHK.EXE

The program generates the B5500.EDA file

3. DIMA.EXE

Inserts the top event to be analysed into the B5500.FLT file

4. CUTIN2.BAT

Generates the cut sets file B5500.CSR on the basis of the CUTIN3.TXT file. Intermediate messages during the program execution are displayed on the file RES1.TXT. The executable file is CUT.EXE.

5. CUT_EV.BAT

Generates the evaluated cut sets file RES2.DAT based on the input file CEVIN.DAT. Intermediate messages during the program execution are displayed on the file RES2.DAT. The executable file is CUTEV.EXE.

6. BCUT_IMP.EXE

Generates the final cut set list in order of magnitude, and calculates the resulting reliability parameter. The resulting file is BRESCUT.DAT. If the top event is the upper top event of the Cause- Consequence diagram, the resulting reliability parameter is the probability of the upper top event. (In the EFP-94 Project it gives the probability per year of rotor overspeed). If other top events are to be analysed, the resulting reliability parameter corresponds to the unavailability of the respective subsystem.

After the calculations are finished the resulting cut sets and reliability parameter at the bottom of the file can be seen by clicking the box 'VIEW'.

The execution of the programs causes a generation of some intermediate files in addition to the above mentioned input and output files.

The minimal list of the files that are necessary for the execution of the whole complex of the programs is the following: *b5500.inp(BONUS), n5500.inp(NORDTANK), bcut_imp.exe, bikhk.exe, bikhkub.exe, binput.exe(BONUS), ninput.exe(NORDTANK), cevin.dat, cut.exe, cut_ev.bat, cutcal.exe, cutev.exe, cutfin.exe, cutin1.com, cutin2.bat, cutin3.txt, dima.exe, f_rates.txt, wpview.exe.* These files must be installed in a sub directory named C:\EFP_94.

The file *f_rates.txt* is the result of the database's Main Menu option, *'Automatic updating failure rates'*. It contains failure rates of the components, calculated in the database on the basis of collected failure data.

3. Database

The database has connections with MS DOS files in several places. In some points it creates **.txt* files which can be read by the executable **.exe* files on the directory c:\EFP_94. The procedure of creating those **.txt* files is connected with either deleting or overwriting some of **.txt* files, that causes generating MS-DOS's messages requiring the confirmation of the actions. It is impossible to avoid those messages and therefore every time, when the user sees them, it is necessary to confirm the action by clicking "Yes". Afterwards the execution will be continued automatically.

These situations appear when the user activates the command button "Automatic updating failure rates" on the Main Menu and "Calculations 1" and "Calculation 2" when performing the reliability calculations.

3.1. Database Management System

The Microsoft Access Relational Database Management System (DBMS) for Windows was used for creating the database for reliability analysis of wind turbines. Its characteristics take full advantage of the graphical power in Windows, giving visual access to data and simple, direct ways to view and work with the information. It has powerful querying and connective capabilities and we can use one query to work with data stored in different database formats and network locations. It allows to automate most tasks easily without the need for programming. For highly specialised data management needs, Microsoft Access uses Access Basic as database programming language.

The key terms for this DBMS, which will be used below in this description, are the following:

- **Table:** A Microsoft Access object that stores data in rows (records) and columns (fields).
- **Form:** An object you can use to enter, change, and view records of data in a custom layout. We can use a form to display record on the screen or in print.
- **Query:** A Microsoft Access object that asks a question or defines a set of criteria about data from your tables.
- **Report:** An object you can use to print records in a custom layout. We can use a report to group records and show totals for groups or for an entire report.
- **Macro:** A list of actions you want Microsoft Access to carry out for you.
- **Access Basic:** The Microsoft Access built-in database programming language.
- **Module:** A collection of one or more Access Basic procedures.
- **Primary key:** A relational database management system such as Microsoft Access has an ability quickly to find and bring together information stored in separate tables. In order for Microsoft Access to work most efficiently, each table in the database should include a field or set of fields that uniquely identifies each individual record stored in the table. In database terminology, this information is called the primary key of the tables. Microsoft Access uses primary key fields to quickly associate data from multiple tables and bring data together.

3.2. Conditions, conceptual and theoretical basis

The existing systems for collecting operational wind turbine data used by the manufacturers are not primarily related to reliability and safety analyses but contain data, which are sufficient for "constant failure-rate methods". These data are based on the assumption that the failure rate is constant throughout the entire lifetime of the equipment and correspond to one-parameter exponential distributions for the times to failure. It was decided also to build the database on this basis, since (1) this approach did not imply big changes in the existing collecting system, (2) there was no evidence to the contrary. Further, it was considered reasonable to extend the contents of the database and make it capable of providing additional reliability related information, which is not directly used for reliability assessments, but can be used for assessing the wind turbine performance and facilitating decision making in other aspects of the performance. This information can be used for answering questions like: Who is the producer of a failed component? Who was the repair man? What was the cost of repair? How many kWh of electricity has been produced?

It was decided to make a FMECA in advance and enter FMECA tables into the database implying that later on the contents of the tables would be corrected on the basis of collected data.

It was adopted also to discriminate two levels of reliability calculations: the 1st and the 2nd level of complexity. The first one presents to the users some simple, quickly obtained reliability indicators, easily understandable for a wide circle of people and easily used (without an additional calculation treatment) for supporting decision making, such as mean and total repair times, the number of failures, failure rates, operational experience and so on. And furthermore, these results from the first level of complexity must be given at three different levels: (1) component, (2) system, and (3) wind turbine as a whole.

The results of the second level of complexity for reliability calculations are the probability of the top event (we limited ourselves to the event "overspeed of the rotor"), the probabilities of failures of specified systems and listings of dominating failure modes in order of decreasing importance with respect to cut set probability. This part of the calculations must be implicitly performed by a separate program activated within the database and based on reliability data from the database. Performing this task assumes that the fault trees have been worked out.

Another point, that should be mentioned here, deals with the procedure of estimating the component failure rates and arises due to absence of failure data until a fixed moment of time in the past. The general formula for assessing the failure rate of the *i*th basic event, λ_{BE_i}, (h^{-1}) is as follows:

$$\lambda_{BE_i} = \frac{\sum_{j=1}^{k} n_{ij}}{m_i T_{Total}}, \qquad (1)$$

where n_{ij} is the number of occurrences of the *i*th basic event for the *j*th WTB; m_i is the number of similar components on one WTB; k - the number of wind turbines of a given type; T_{Total} (h) -total operational repair time for all k WTBs. So as to understand the link between a basic event and a component, it is enough to say that a basic event is completely defined by the system, component, and the failure mode, i.e. the same component can belong to different basic events.

The parameter T_{Total} can be calculated in different ways depending on particularities of the data collecting. So, if failure data are collected from all wind turbines in operation, then $T_{Total} = \Sigma^k t_j$, where t_j is the total time of operation of the *j*th wind turbine of a given type. In our case the failure data are collected from a fixed time in the past $\mathbf{t}_{Past}$ and therefore we have to take into account five different wind turbines life lines (see Fig. 3.1). The total operational time should be assessed according to the formula

$$T_{Total} = (t_{Now} - t_{Past})N_{WTB} - \sum_{i=1}^{N^f}(t_{Now} - t_i^f) - \sum_{i=1}^{N^s}(t_i^s - t_{Past}), \qquad (2)$$

where $\mathbf{t}_{Past}$ is defined as the date of reporting the first failure in the database, N_{WTB} is the number of wind turbines under observation, N^f is the number of wind turbines removed from operation within the interval [$\mathbf{t}_{Past}$, $\mathbf{t}_{Now}$], N^s is the number of wind turbines put into operation within the interval [$\mathbf{t}_{Past}$, $\mathbf{t}_{Now}$]. The remaining variables are shown in Fig. 3.1.

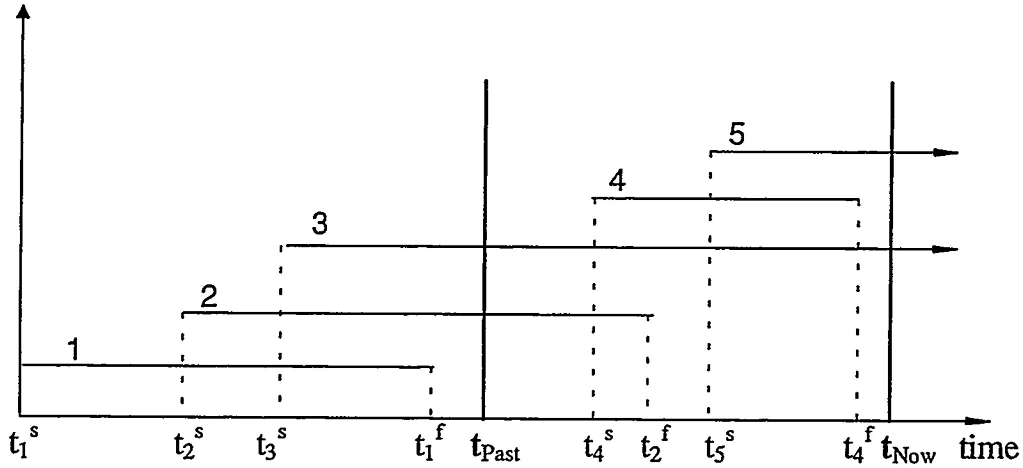

Figure 3.1. *Possible wind turbine's life lines*
t_i^s - *time of the start of the ith wind turbine operation,* t_i^f - *the stop of the operation,* t_{Past} - *time of the beginning of the data collection,* t_{Now} - *present time*

For quantification of the system unavailability the models used for the basic events must be defined. It has been accepted to distinguish between four classes of basic events (also called "component classes") [1,2]: 1) non-repairable, 2) monitored, 3) periodically inspected, and 4) constant unavailability or unavailability per demand. We limited ourselves to the following classes: non-repairable and periodically inspected. The monitored ones are excluded because they are not found in the two types of wind turbines analysed in the project. As for unavailability per demand, these events are so rare that statistical data are absent and failures in the part of wind turbines working per demand are revealed as a rule during inspections.

3.3. Logical data model

In order to meet the conditions and theoretical requirements, five basic tables (Tables 3.1-3.5) and several subsidiary ones were created. The basic tables are actually the database itself and contain the basic information needed to make a decision on wind turbine performance and reliability in particular. The main reason for dividing the database into a series of tables is to avoid the redundancy in data, but nevertheless as we can see some of the fields are repeated to link the tables and automate filling out some of the fields. The links are provided by *Primary* and *Foreign keys*.

The table fields, contain the codes of options, where it was possible to classify them, but not full names and definitions. So, for the fields *System, Component, Failure modes, Failure causes, Detection methods, Responsibility, wind turbine modes* all options can be foreseen in advance and classified. Therefore these fields comprise only short codes. The decoding tables for these fields we called subsidiary tables. Except for the function of decoding they serve as menu options under data entry.

FMECA Table — Table 3.1

Primary key (column 1)

1	2	3	4	5	6	7	8	9	10	11	12
BE no.	BE name	Ref no.	Systm	Compo-nent	Fail. mode	Fail. cause	Detect. method	Respon sibility	Likeli hood	Sever ity	Basic event type
1											
i											

Main Table — Table 3.2

Foreign keys (columns 2, 3); Foreign key (column 5)

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Rec. no.	BE no.	WTB ID	Syst	Comp onent	Fail. mode	Comp no.	Date	kWh	Work order	Who made	WTB mode	Repair time	Repair man	Re-mark
1														
j														

WTB Table — Table 3.3

Primary key (column 1)

	1	2	3
	WTB ID	Date of start	Date of finish
record 1			
record k			

Component Table — Table 3.4

Primary key (column 1)

	1	2	3	4	5	6
	Component	Component name	System	Test Interval	Number	Price
record 1						
record n						

Initiating Events — Table 3.5

	1	2	3	4	5
	Code of IE	Name of IE	Reference no.	Date of updating	Rate of IE
record 1					
record m					

Every type of wind turbine has its own five basic tables. So, if there are four types of Nordtank wind turbines, which means that there are four sets of the basic tables.

The contents of the FMECA and the Main table do not require any detailed explanation, since FMECA is a well known procedure and the Main table is just all of the available reliability related information from the manufacturers. The only field in the FMECA table demanding an explanation is the field 3, "Ref. no." (Reference number). It is intended to indicate, that the reliability data for some different basic events having the same component and failure mode, but different systems, have to be considered as originated from the same sample. For example, if we have identical oil filters installed in different systems and assume that the conditions of operation are similar, then all of the failures, in spite of which system they belong to, have to be registered in one common sample, which is marked by a specific "reference number". However, if the operating conditions, environment or maintenance strategy are different and influence the failure rate considerably then the failures must be treated individually with separate reference numbers.

In order to link two tables, the repetition of one field in the two tables is enough, i.e., for the FMECA and the Main table it would be enough to link them through the field "BE no.". But in this case it would be necessary to enter basic event numbers into the Main table by hand. But these numbers are foreign elements for the staff and should not be kept in mind. A more natural way is to enter for each failure: System, Component and Failure mode, which define completely a basic event, and fill in the field "BE no." automatically. In this case the redundancy is justifiable.

Tables 3.3-3.5 were mainly created to provide for quantitative reliability calculations. So, the field "Date of start" contains numbers for t_i^s (2), "Date of finish" for t_i^f (2), and "Test interval" for assessing the (un)availability of periodically inspected components, "Number" for m_i (1). The number of wind turbines under concern, N_{WTB}, is equal to the number of records in the WTB table. Table 3.5 contains the data characterising initiating events and other conditions, like extreme wind speeds or earthquakes, which are external events in relation to the wind turbines, and their reporting is not a concern of the staff. But nevertheless the rates of initiating events are necessary for the reliability calculations. Therefore this table must be created and the rates should be periodically updated to take into account any new information influencing the failure rates. In order to remind the users to do the updating, the field "Date of updating" was added, which is the date of the last updating of the failure rates.

3.4. Database objects

The database has six types of objects: tables, queries, forms, reports, macros and modules. They are briefly described below.

3.4.1. Tables

The tables are Microsoft Access objects that in our case store reliability and reliability related information. The whole list of the tables is presented in appendix 3.

3.4.2. Queries

With a query we ask a question about the data stored in the tables. The way we design a query tells Microsoft Access exactly which data to retrieve. Queries in the current database are used to extract desired data, that afterwards are presented in the reports. The whole list of the queries created is presented in appendix 3.

3.4.3. Forms

A form provides an easy way to view data. We can view all the values for one record in Form view, or we can switch to the Datasheet view of the form to see all records for that form. Using a form is also an efficient way to enter data; it can save time and prevent typing errors. For example, rather than type values for all fields, we can create lists in the form from which you choose values. A form offers the most convenient layout for entering, changing, and viewing records in the database.

16 different forms were created which together with the reports constitute the user interface. Using the forms is easy since they are of the same concept as much of other Microsoft software. Unlike the other Access objects a description is not necessary in this report since they can be understood during the use of the database.

3.4.4. Reports

Creating a report is an effective way to present data as a printed document. Although we can also print forms and data sheets, reports give us more control over how the data are displayed and offer greater flexibility in presenting summary information. There are a number of reports in the database:

Report	**Explanation**
Component Smallest	The report is a result of the chain of choices at the component level "*Specific WTB-Specific Component*"
Component Small	The report is a result of the chain of choices at the component level "*Specific WTB-All Components*"
Component	The report is as a result of the chain of choices at the component level "*All WTBs - All Components*"
System Small	The report is as a result of choice at the system level "*Specific WTB*"

Report	Explanation
System	The report is a result of choice at the system level "*All WTBs*"
WTB Small	The report is a result of choice "*Specific WTB*" at the level "WTB as a whole"
WTB	The report is a result of choice "*All WTBs*" at the level "WTB as a whole"

3.4.5. Macros

Using macros we can make forms, reports, and other database objects work together more intelligently. A macro automatically carries out a task or a series of tasks for the user. Each task that we want Microsoft Access to perform is called an action. When we run the macro, Access carries out the action in the sequence they are listed, using the objects or data we have specified.

The whole list of macros is presented in appendix 3.

3.4.6. Modules

A module is a collection of declarations, statements and procedures stored together as one named unit.

The modules included in the database are presented in the table below:

Modules	Explanation
Pause	Is needed to run the series of executable programs one by one intended for reliability analysis. The programs are in the c:\EFP_94 directory and are the following: *binput.exe, bikhk.exe, dima.exe, cutin2.bat, cut_ev.bat, bcut_imp.exe*
Top Event 5001 Top Event 5002 Top Event 5003 Top Event 5004 Top Event 5005 Top Event 5006 Top Event 5007	Modules are needed to run the set of queries for selecting the information intended to be the source of data under the forms *Top Event XXXX-1* and *Top Event XXXX-2*, where *XXXX* is Top Event number according to the Cause-Consequence diagram

Modules	Explanation
Top Event 5008 Top Event 5010 Top Event 5011	
Updat_date Updat_rate	Modules are intended to check the date of the last updating of the rates of initiating events. In case the last updating was more than 90 days ago, the system will give out the message.

3.5. Interface

The user's interface is nothing but a set of forms and reports. The forms are used not only for customising the layout for entering, changing and viewing records but also for organising the dialogue in the form of menus. Fig. 3.2 shows all the options of the *Main menu* and one branch of choices at the component level and gives some information about the concept of the dialogue. The result of any end state in the chain of choices is an outcome report.

It is impossible to foresee in advance the preferences of all possible users concerning the outcome results (content of the reports, totals, combination of results and so on). Therefore the selected reports contain the most frequently required information. In order to meet the user requirements not foreseen, there is a possibility to reject the use of the customised menu and use the standard Microsoft Access built-in facilities which cover the widest range, but often does not give the most efficient way of extracting a particular piece of information needed.

4. Conclusions

The work on methodology and database within this project implied much effort in order to obtain a proper linking between the respective parts of the database but the work resulted in an operational integrated database and program facility. The integrated database system was implemented on PCs and tested by the two wind turbine manufacturers participating in the project.

The methodology and database comprise a fairly unique facility, which provides advanced on-line reliability analysis of the safety systems of the two wind turbine types included in the project, using reliability data, based on maintenance and repair reports in addition to statistical analysis of the empirical data. The reliability anlyses can be performed on a component, subsystem and safety system level as required.

The integrated database has proved to be a very efficient tool for identifying weak points in the design or maintenance of wind turbine safety systems.

It should be emphasised however, that the present successful application of the integrated database system on wind turbine safety systems is just one example. The integrated methodology and database has great potential for applications in the design and maintenance planning also on many other technical systems of even very different types.

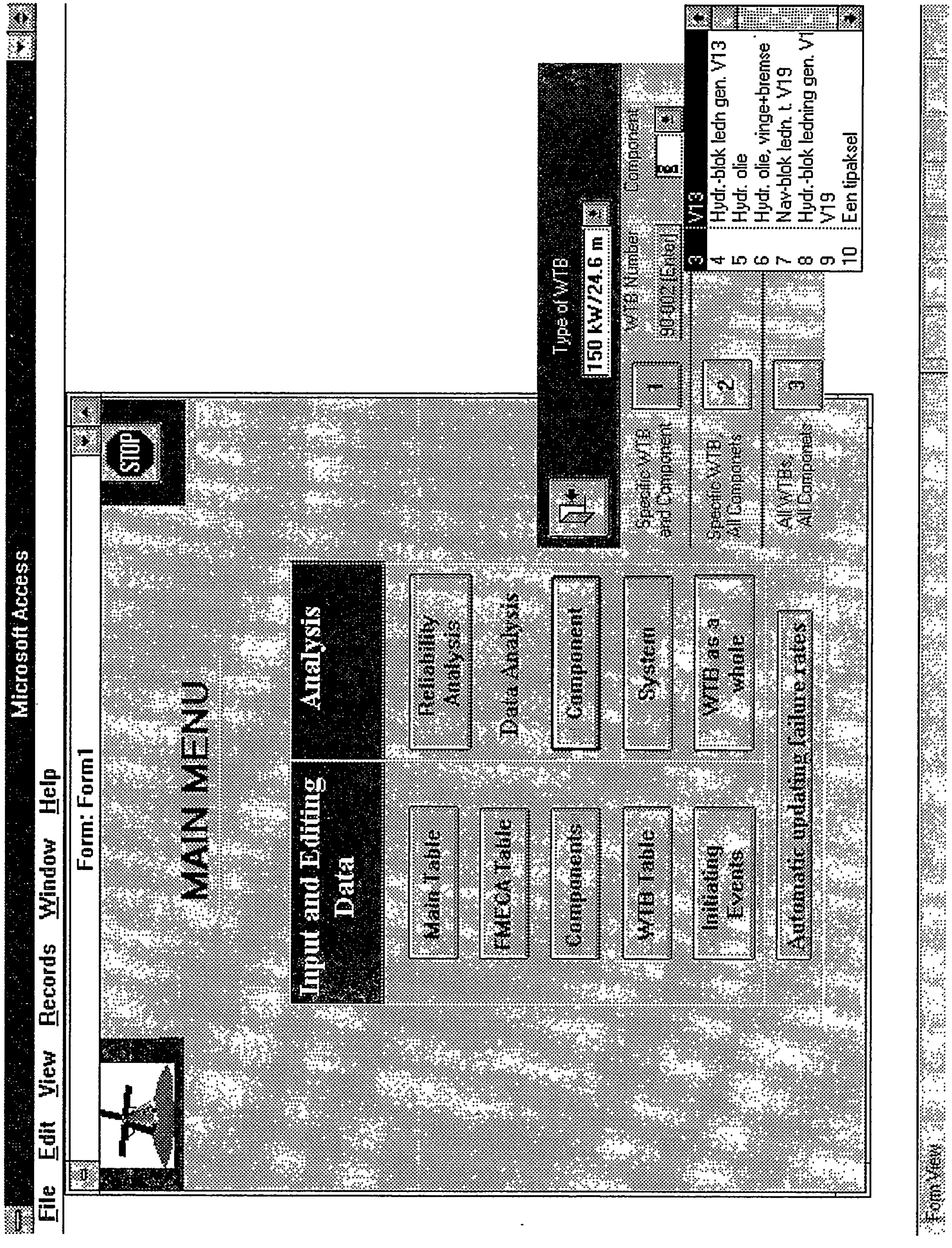

Figure 3.2. Main menu and one branch of choices at the component level.

5. Acknowledgement

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Abstract (max. 2000 characters)

A project sponsored by the Danish Energy Agency was carried out in co-operation with two Danish wind turbine manufacturers. In accordance with the purpose of the project a methodology for the analysis of the reliability of the safety systems of wind turbines was established in addition to a supporting database for reliability data of wind turbine components and equipment. The methodology and database were implemented on PCs and comprise a fairly unique facility, which provides advanced on-line reliability analysis of the two wind turbine safety systems using realistic reliability data, based on maintenance- and repair reports in addition to statistical analysis of the empirical data. The reliability analyses can be performed on a component, subsystem and safety system level as required. The integrated methodology and database has great potential for applications for design and maintenance planning also on other technical systems than the ones analysed within this project.

Descriptors INIS/EDB

BRAKES; DATA BASE MANAGEMENT; FAILURE MODE ANALYSIS; RELIABILITY; SAFETY; WIND TURBINES

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